INTEGRATION OF SUBSCALE FLIGHT TESTING IN DESIGN EDUCATION

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Abstract

Traditional final aircraft design courses have focused on the development of a "paper" product. This paper reflects on the development of a program where students are required to design, build and fly a model of the aircraft they design. Experience has suggested that the students were motivated towards such a task and generally found it to be a worthwhile learning experience. Such a process provided a degree of closure to the design loop that would not otherwise be present. Additionally, such a program has been found to be an excellent focus for research work in various areas and for collaboration with industrial partners and other universities.

1 Introduction

Aerospace design education at Linköping University is a relatively specialised area within the broader mechanical engineering program. As with many other such education programs the students are exposed to courses in aerospace fundamentals such as aerodynamics, structures and flight mechanics before undertaking a final aircraft design project. It is recent experience with this final design project that is the subject of this paper.

Rather than conduct a more traditional "paper" project for this final project, in the last two years work has instead been conducted on developing a program where the students are required to actually build and fly a physical prototype of the vehicle they design. Such a program was inspired in part by the experience of other universities such as North Carolina State University [3, 6] and Stanford University [4, 7]. This relatively novel type of program was considered to offer several principle benefits:

- tends to motivate students by enabling them to see the fruits of their labours
- enables integration of undergraduate and postgraduate research around one common project
- enables integration of skills across disciplinary areas within the university
- offers significant areas of collaboration with industry partners
- significant marketing and exposure benefits.

The development of a course that required students to build a prototype vehicle began in 1998 with a solar powered flying wing demonstrator (see Fig. 1). This project required students to investigate the development of a manned observation vehicle using solar power as a sole means of propulsion. The students were required to build a small scale demonstrator to show the feasibility of their proposal.

The response to this project was positive from both students and local industry. As such, it was decided to develop a capability to build and test such subscale demonstrators as a standard requirement for future aircraft design courses.

Fig. 1 *Sunrazor* solar powered flying wing

One significant addition has been the development and integration of a flight test instrumentation package in order to allow more than just qualitative data to be obtained. Such a procedure offers several significant additional advantages. Most significant of these is the ability to check students design predictions with a good degree of accuracy on the actual vehicle. This has been found to strongly motivate the students and provide a degree of closure to their work. Additional benefits are that such a project enables the involvement of postgraduate research in the development and testing work and also offers other specialist areas within the university such as control systems and electronics specialisations to become involved. One final advantage in this particular instance was the fact that a local industrial partner had already been working to an extent with such a concept and was keen to seek university support for such a project.

2 Project Description

In order to develop the set of flight test instrumentation there was a requirement for a testbed vehicle upon which such development could proceed. As will be described in a subsequent section the project was thus established along industrial lines as much as possible such that the university department became a customer and the students were divided into various contractors vying to meet the requirement specification. In summary, this requirement called for a robust, safe aircraft with docile handling qualities capable of flight for at least two minutes at 50% throttle using an electric motor. A set of other secondary performance and structural requirements were also stipulated. Payload was a defined set of instrumentation, a summary of which is provided in Table 1.

Due in part to academic demands the course was split into two phases: preliminary design and detail design. The basic requirements of each phase are summarised in Table 2. The project management in each phase differed due in large part to the change in emphasis from initial concept exploration to more detailed analysis of the selected configuration.

2.1 Research Goal

This project enables the integration of work undertaken both at undergraduate and postgraduate level. In this instance, the intention is for postgraduate work to attempt to show the validity of using such a platform for prediction of unusual aircraft configuration characteristics early in the design process (see [5]). Such demonstrator programs have been increasingly common in recent years; the Boeing X-36 28% scale fighter [8], 1/2 scale Predator UAV [2] and Boeing/Stanford University Blended Wing Body [7] being typical examples. Among the benefits of such free-flight testing are that it enables preliminary closed loop testing to be performed that otherwise could not be performed until development of the fullscale aircraft or a sophisticated, costly simulator. It is proposed that such subscale flight testing can form part of the preliminary development tool continuum as illustrated in Fig. 2. While there are clear limitations to what such testing can achieve it is the intention to demonstrate nonetheless that such testing can be of benefit in areas such as field performance and high risk testing such as high-alpha and spins.

A platform for testing of novel systems or flight control architectures enables risk reduction before development of such a system for a fullscale vehicle. Additionally, the increasing development of UAVs means that there is a significant market need for systems capable of operating in this smaller size regime.

Instrument	Description	Weight (g)
Sensym 142SC15A	Absolute pressure sensor	23
Sensym HCXM010D6V	Differential pressure sensor	14
Crossbow DMU-AHRS	Attitude and heading reference system	570
BI Technologies 7286	Potentiometer	21
Onset Tattletale TFX-11	Data logger	76
Mätforum PR-30	Pitot-static tube	38

Table 1 Instrumentation package

Preliminary Design	Detail Design
Configuration layout	Detail configuration and systems
Preliminary systems configuration	Analysis of key areas (structural, aerodynamics, propulsion)
Analysis of alternatives (systems, configuration)	Component and system testing
	Construction of prototype
	Flight test

Table 2 Requirements for each phase of the development process

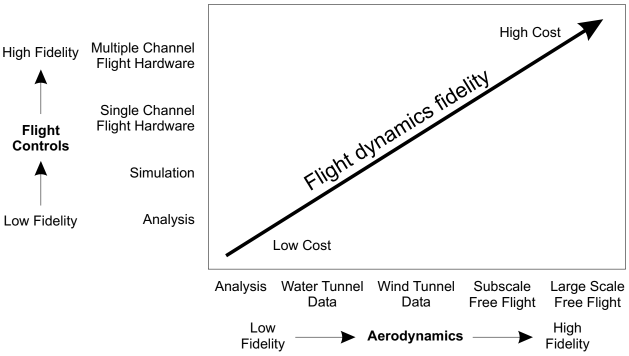

Fig. 2 Achievable levels of flight dynamics prediction

2.2 Design Tools

The basic set of tools utilised was common to any other final aircraft design course. However, because the aircraft was actually required to fly it was felt to be advantageous to perform as deep an analysis as possible within time and cost constraints and without exceeding the students abilities.

It was considered impractical to expect the students to develop the necessary software codes to perform this level of analysis within the limited timeframe available. In order to deal with this problem a set of simple software codes were made available that the students were expected to utilise. These programs consisted of:

- sizing program for determining effect of changes on configuration
- lifting line code for lift and drag analysis and control surface sizing analysis
- two and three degree of freedom fluter codes for wing flutter analysis
- linear flight dynamics model for stability and control analysis.

The codes were made as simple as possible to interact with, in this way the students could concentrate on *using* the codes rather than spending a large amount of time understanding in detail their operation and interfaces. As an example, Fig. 3 shows the interface to the flight dynamics module where each dialog box represents different characteristics such as geometry, aerodynamics, weight and balance and so on. All of the programs used were by neccessity rather simple, however it was felt that this made them easier for the students to interact with and understand the fundamental underpinnings behind them.

2.3 Design Philosophy

The design philospy is termed “design-build-test-fly". The goal was for the students to calculate using rapid prediction methods necessary dimensions for components to withstand the predicted loads and then undertake a physical component test to verify that these loads can be met. This testing was considered to be an important part of the project and students were encouraged to think carefully about the tests they intended to

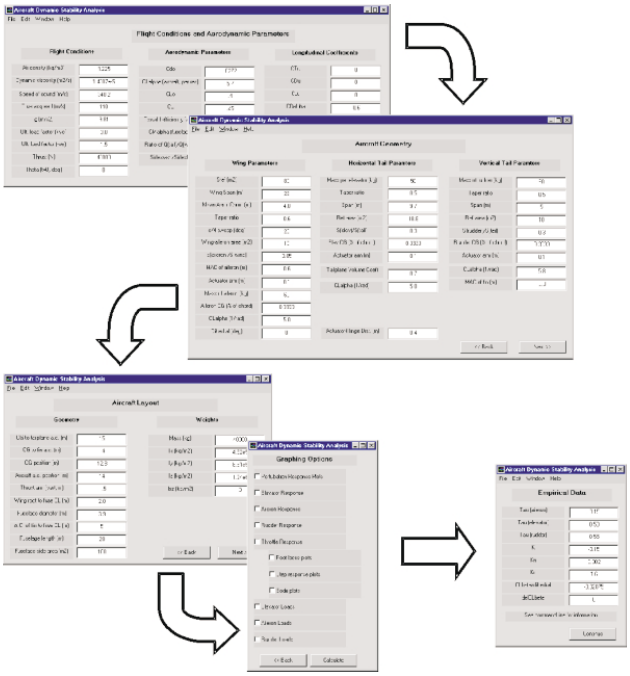

Fig. 3 Flight dynamics model interface

conduct. This was encouraged by insisting that students submit a test planning document, which outlined what was going to be tested, what results were expected and how the test would be conducted. This testing process is illustrated in Fig. 4.

The design emphasis was based on the supervisors' past experiences and expectations for this project. As a result, all students were actively encouraged to consider the influences of aeroelasticity, electromagnetic interference and emergency recovery systems. The latter in particular was considered crucial, not only was it considered deterimental to loose the aircraft but in the worst possible failure scenario the valuable payload must survive. As such, an emergency parachute system and honeycomb encasement of the most delicate payload was undertaken. The emergency system could be roughly classed into three areas depending on the criticality and probability of occurence of a failure (1 = Mild, 2 = Significant, 3 = Critical). This simplistic classification of the safety systems is summarised in Table 3.

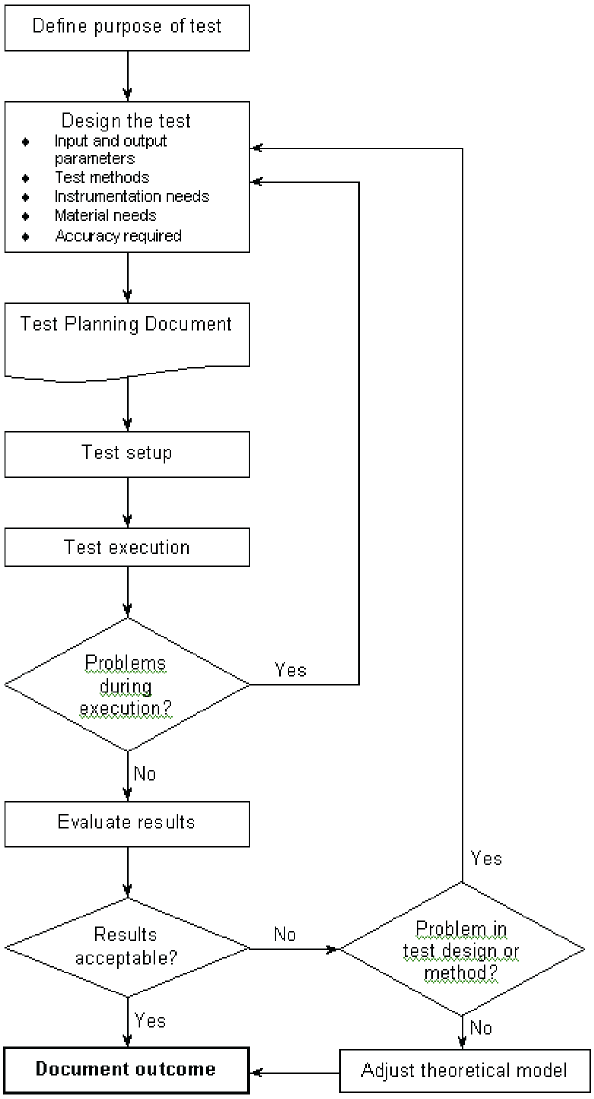

Fig. 4 Test planning procedure (adapted from [1])

Level	Classification	Protection systems
1	**Mild**; temporary loss of control; flight recoverable	PCM radio; backup radio modes
2	**Significant**; long term loss of control; system failure requiring immediate termination of flight; recovery of vehicle is priority	Parachute recovery system
3	**Critical**; multiple critical system failures; damage minimisation	Crashworthy structural design; honeycomb encapsulation of critical cmpts

Table 3 Safety levels and protection systems

2.4 Test Procedure

As indicated previously, testing was considered to be an integral part of the design process. This is true both for subsystem testing right though to final aircraft flight testing. In summary, students were expected to perform testing in the following areas:

- Wing tests
  - Ultimate load testing: to demonstrate compliance with critical loading requirements
  - Vibration testing: to extract natural mode frequencies for aeroelastic analysis
- Inertial testing: to validate inertia predictions using a rig based on the simple and compound pendulum methods, designed by the students.
- Electromagnetic interference: test for magnetic and electric field strengths for different cable configurations and shielding both for DC and AC of varying magnitudes.
- Parachute system: conduct drop tests of parachute alone to validate predictions and test ejection mechanism using fuselage mockup.
- Propulsion: design and build a test rig to test for static thrust of installed configuration.
- Crash testing: fuselage drop test to confirm crashworthiness characteristics are within limits.

All of these tests were expected to be conducted primarily by the students, although considerable supervision was required, especially in using the required instrumentation. Additionally, time constraints meant that some tests had to be restricted in order to complete the many other tasks that were expected of the students.

3 Project Management

Managing such a task as described in the previous section requires many of the same skills used in industrial projects in terms of time and cost control. However, unlike in an industrial environment the students typically have a lower level of experience both from a technical perspective and in their ability to work independently.

In order to create as realistic a learning environment as possible, the project was based around a customer issuing a requirement to competing prime contractors (two student teams) who then had to work with subcontractors (in the case of the preliminary design phase, a systems team). In this way the students were exposed to both competition and to the necessity to communicate both with fellow team members and with other teams.

In order to aid in the sharing of information and to establish problem areas, brief design reviews were held once a week during the preliminary design phase and once a month during the detail design phase. These generally helped to raise key issues of concern and priority areas. Additionally, they helped in sharing ideas between teams.

One additional factor that contributed to the realisation of this project was the international mix of students. Typically around 50% of students undertaking the aircraft design specialisation are from outside Sweden. In the most recent year a total of five european nationalities were

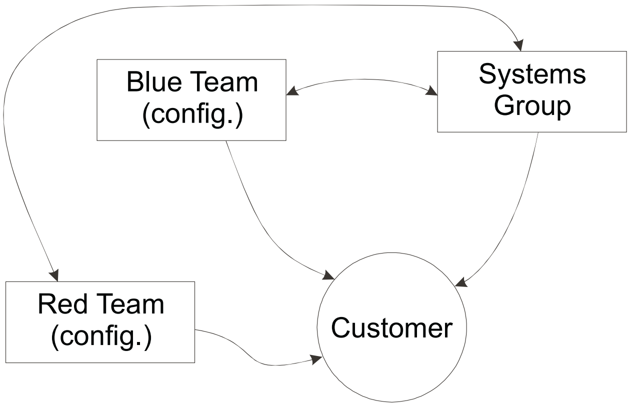

Fig. 5 Information flow in preliminary design phase between teams

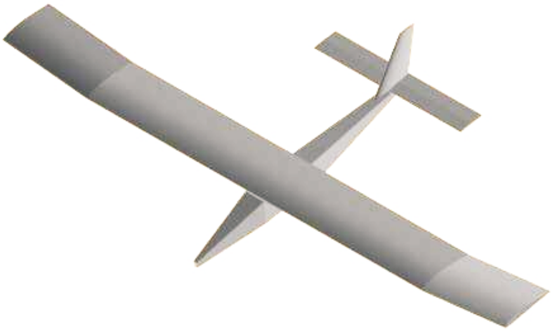

Fig. 6 *LocalHawk* flying testbed

represented. Clearly, the cultural and educational background varied widely amongst the group and adjustment was required to achieve an effective working group.

3.1 Preliminary Design Phase

The primary purpose of the preliminary design phase was to determine the configuration layout and obtain preliminary systems selection, installation and layout information. In order to best encourage the students and to generate alternative ideas and concepts, three teams were established: two competing configuration teams and a systems team. The information flow that was desired in such an environment is illustrated in Fig. 5.

The winning configuration was a simple high-wing glider type configuration. This resulted in a safe, well known configuration of good low speed flying qualities. The configuration is illustrated in Fig. 6.

3.2 Detail Design Phase

For the detail design phase a more traditional team breakdown was selected, consisting of four teams:

- Configuration
- Fuselage
- Wing
- Empennage team.

Each team was responsible for detail design and assembly of their component of the aircraft. The configuration team had responsibility for overall aircraft issues such as stability and control. This is reflected in the work breakdown structure shown in Fig. 7.

3.3 Autonomous Learning Environment

Unlike teaching of the engineering fundamentals, this problem-based approach to design education requires a great deal of flexibility and autonomy both from students and teachers. Such autonomous learning is essential because of the limited time available from the supervisors, and in any case has been shown by numerous researchers (see for example [**?**]) to be a useful way of teaching at such a level. This autonomous learning requires a shift away from teacher-direction to using the teacher as a resource. Among the lessons from research into autonomous learning are the necessity for creating a flexible working environment for the students and ensuring the expectations of the teachers are clearly defined. This latter point is somewhat problematic in this type of project where changes need to be made as the project progresses and greater understanding of critical areas is developed.

A great deal of monitoring by teaching staff

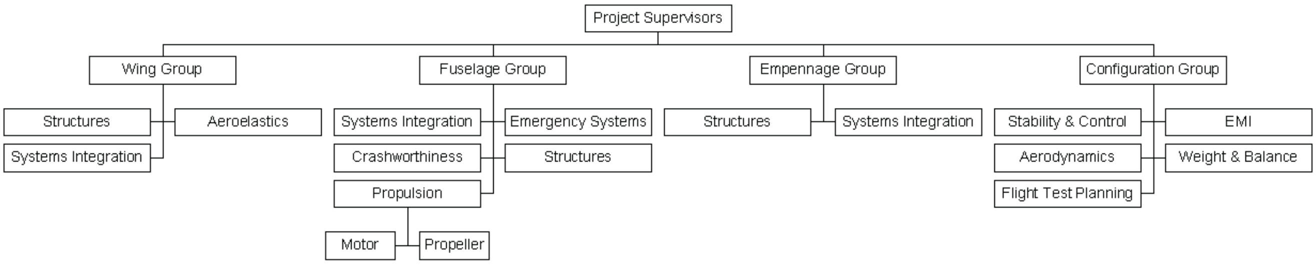

Fig. 7 Work Breakdown Structure in Detail Design Phase

was required to ensure the learning environment was adequate as the project developed. This was complicated by the fact that each student reacted differently and of course because of widely varying cultural and educational backgrounds. As with any such project these were students who willingly and readily took up the challenge while there were others who rapidly became daunted and required close supervision. Interestingly, it was observed that generally speaking the familiarity or otherwise with a particular subject area appeared to have little impact on the students' motivation. In some cases the students had the technical background in a particular subject area but were unmotivated, in others students had very limited technical knowledge but excelled.

Experience to date suggests that to maintain motivation of independent, autonomous learners requires ensuring they are given the room to develop concepts and ideas with teacher support as required. For less motivated students however a more traditional approach appeared necessary, where requirements were clearly stipulated thus severely limiting flexibility.

3.4 Document Control

An understanding of the importance of document traceability as a core part of the quality assurance and certification process for a real aerospace project was considered to be one of the priorities, and an area that has perhaps been neglected in more traditional courses. A standard format was required for all reports in order to encourage uniformity in both report format and ensure the required content was presented. This content was stipulated such that in latter years it would be possible to replicate any test undertaken and to follow the design process.

As with any such project, the students rapidly discovered the neccessity of communicating the latest design information to others as it became available. The internet has been utilised as a cost effective and rapid means of achieving this goal.[1]

4 Lessons Learned and Further Work

This type of project-based work placed new demands on both students and staff that required some adaptation. Principally, it was surprising the difference in reactions between students to this learning environment. Reactions varied from looking positively and proactively to the task at hand to being overwhelmed and feeling incapable of progressing. This created special problems for the teachers, as flexiblility was required in discussions with each individual. However, it is felt that it was still a necessary part of the learning process to give the students as much independence as possible as this was one goal of the course. Key lessons learned include:

- Clear and well-defined goals are required and should be adhered to as rigidly as possible through the course. Students generally appeared not to appreciate “moving the goalposts".

- Flexibility is required towards the details, especially when it becomes clear that one

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[1] See http://www.flumes.ikp.liu.se/ cammu/tmal53/

goal is not achievable with the time constraints. This of course must be dealt with carefully for it not to conflict with the previous point.

- Enabling students to be involved in the whole design process is a motivating and positive objective.
- Students should be allowed to choose areas of their own interest for work, as long as they remain within the goals of the project. For example, some students had a preference analysis while others preferred testing. In these cases, in order to maintain motivation students were given the opportunity to work in areas they were interested *but* were still required to have some contribution in other areas so as to maintain a broad understanding of the process.
- Conflicts with other student courses creates problems in focusing the students on a fixed timeline but is in most likelihood unavoidable given the many demands on students time in their final year of studies.

The education program is continually adapting and changing in order to make the course most beneficial for both students and the department. Experience from the course in the past two years has offered valuable lessons in what can and cannot be expected of the students and staff alike. At the same time, expectations from the staff have been increasing in each year as confidence in the validity of the method is increased.

Further work is anticipated in developing greater capabilities in the following key technical areas:

- Parachute recovery systems
- Data acquisition and analysis
- Advanced materials suitable for use in a university enviroment
- Failure modes and effects analysis for improving system reliability
- Novel test techniques suitable in such an environment, such as car-top testing.

Additionally, developing stronger ties with local industry is considered a necessity to ensure the program remains focused on their needs for graduate engineers. Also, potential collaboration with other universities in Sweden has been raised. This offers interesting possibilities and challenges by combining different areas of research and students of different academic backgrounds who are geographically separated. Recent experience of the multi-national Loughborough University and Virginia Tech programs has however suggested that such collaboration should be feasible. [2]

5 Conclusion

Experience with this type of program has generally been positive, but a number of important lessons have been learnt in the implementation of such a program. A new way of learning both for students and staff has proved the need for flexibility. At the same time, greater oversight is required than in a postgraduate or real working environment. The cost of such a program (especially in terms of acquiring suitable instrumentation) is high initially, but can be amortised over several years such that the cost-benefit is such to make the program worthwhile. Perhaps the greatest benefit, is that having a flying vehicle at the end of the program is a great motivator and provides a focus point for research in a number of different areas.

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